

## Preparation of nanocrystalline lithium titanate spinels

The present invention relates to a process for preparing  
5 nanocrystalline lithium titanate spinels by reacting lithium hydroxide and titanium alkoxides at elevated temperature in a reaction mixture which forms water of reaction.

The preparation of nanocrystalline lithium titanate spinels by  
10 reacting lithium ethoxide and titanium(IV) alkoxides by the sol-gel method at elevated temperature is known from Electrochemical and Solid-State Letters (2002), 5(2), A39 - A42.

Disadvantages of this process are the gel formed and its work-up.  
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It is an object of the present invention to remedy the abovementioned disadvantages.

We have found that this object is achieved by a new and improved  
20 process for preparing nanocrystalline lithium titanate spinels, which comprises reacting lithium hydroxide and a titanium alkoxide at elevated temperature in a reaction mixture which forms water of reaction.

25 The process of the present invention can be carried out as follows:

The first component for the reaction forming water of reaction, the titanium alkoxide and lithium hydroxide can be placed in a  
30 reaction vessel first, after which the second component for the reaction forming water of reaction is added and the reaction is completed at elevated temperature, generally from 50 to 180°C, preferably from 60 to 150°C, particularly preferably from 70 to 140°C, with the proviso that the upper temperature limit is  
35 determined by the reflux temperature of the total reaction mixture, and a pressure of from 0.1 to 3 bar, preferably from 0.5 to 2 bar, particularly preferably at atmospheric pressure.

The solid obtained, viz. the nanocrystalline lithium titanate  
40 particles, are generally isolated by evaporation of the reaction mixture and subsequent drying, preferably spray drying.

The molar ratio of titanium alkoxide to the first component for the reaction forming water of reaction is generally from 0.8:1 to  
45 50:1, preferably from 0.95:1 to 10:1, particularly preferably from 1:1 to 5:1, in particular from 1:1 to 3:1. The molar ratio of the first component to the second component for the reaction

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forming water of reaction is generally from 3:1 to 0.95:1, preferably from 2.5:1 to 1:1, particularly preferably from 1:1 to 1.5:1.

5 The reactions forming water of reaction can be, for example, esterifications, amide formation reactions or etherifications, but are preferably esterifications, particularly preferably esterifications among components which are present in the reaction mixture, for example ether alcohols.

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In the case of an esterification reaction as source of the water of reaction, preference is given to firstly placing the alcohol component in the reaction vessel as first component, for example together with the titanium alkoxide and, if desired, the lithium

15 hydroxide and adding an organic acid as second component, preferably dropwise, to the mixture of the abovementioned three (3) components.

Lithium hydroxide can be used in solid form, for example as  
20 powder, spheres, pellets or in any other shapes. The lithium hydroxide used is generally dry or water-free, i.e. aqueous lithium hydroxide solutions are not used and no water is added.

Suitable titanium alkoxides are, for example, titanium  
25 tetramethoxide, titanium tetraethoxide, titanium tetra-n-propoxide, titanium tetraisopropoxide, titanium tetra-n-butoxide, titanium tetraisobutoxide, titanium tetra-sec-butoxide, titanium tetra-tert-butoxide, titanium tetra-n-pentoxide and titanium tetraisopentoxide, preferably  
30 titanium tetraethoxide, titanium tetra-n-propoxide, titanium butoxide, titanium tetra-sec-butoxide and titanium tetra-tert-butoxide, particularly preferably titanium tetra-n-propoxide, titanium tetraisopropoxide, titanium tetra-n-butoxide and titanium tetraisobutoxide, or mixtures  
35 thereof.

Suitable first components for the reaction forming water of reaction are organic solvents, suspension media or dispersion media, in general polar organic solvents, suspension media or  
40 dispersion media, in particular aliphatic alcohols, ether alcohols or mixtures thereof having a boiling point below about 300°C under atmospheric pressure. These can be used in anhydrous form or preferably in commercial form which is not free of water, but no additional water is added.

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- Suitable alcohols are C<sub>1</sub>-C<sub>8</sub>-alkanols, preferably C<sub>1</sub>-C<sub>4</sub>-alkanols such as methanol, ethanol, n-propanol, isopropanol, n-butanol, isobutanol, sec-butanol or tert-butanol, particularly preferably C<sub>1</sub>-C<sub>3</sub>-alkanols such as methanol, ethanol, n-propanol or
- 5 isopropanol, in particular methanol or ethanol.

- Suitable ether alcohols are all known glycol ethers such as ethylene glycol monomethyl ether, ethylene glycol monoethyl ether, ethylene glycol mono-n-propyl ether, ethylene glycol
- 10 monoisopropyl ether, ethylene glycol mono-n-butyl ether, ethylene glycol monoisobutyl ether, ethylene glycol mono-sec-butyl ether, ethylene glycol tert-butyl ether, diethylene glycol monomethyl ether, diethylene glycol monoethyl ether, diethylene glycol mono-n-propyl ether, diethylene glycol monoisopropyl ether,
- 15 diethylene glycol mono-n-butyl ether, diethylene glycol monoisobutyl ether, diethylene glycol mono-sec-butyl ether, diethylene glycol tert-butyl ether, preferably ethylene glycol monoethyl ether, ethylene glycol mono-n-propyl ether, ethylene glycol monoisopropyl ether, ethylene glycol mono-n-butyl ether,
- 20 ethylene glycol monoisobutyl ether, ethylene glycol mono-sec-butyl ether, ethylene glycol tert-butyl ether, diethylene glycol monoethyl ether, diethylene glycol mono-n-propyl ether, diethylene glycol monoisopropyl ether, diethylene glycol mono-n-butyl ether, diethylene glycol
- 25 monoisobutyl ether, diethylene glycol mono-sec-butyl ether and diethylene glycol tert-butyl ether, particularly preferably ethylene glycol mono-n-propyl ether, ethylene glycol monoisopropyl ether, ethylene glycol mono-n-butyl ether, ethylene glycol monoisobutyl ether, ethylene glycol mono-sec-butyl ether,
- 30 ethylene glycol tert-butyl ether, diethylene glycol mono-n-propyl ether, diethylene glycol monoisopropyl ether, diethylene glycol mono-n-butyl ether, diethylene glycol monoisobutyl ether, diethylene glycol mono-sec-butyl ether and diethylene glycol tert-butyl ether, in particular ethylene glycol monoisopropyl
- 35 ether, ethylene glycol monoisobutyl ether, ethylene glycol tert-butyl ether, diethylene glycol monoisopropyl ether, diethylene glycol monoisobutyl ether and diethylene glycol tert-butyl ether.
- 40 Suitable second components for the reaction forming water of reaction are organic acids such as carboxylic acids, for example formic acid, acetic acid, propionic acid or orthocarboxylates such as trimethyl orthoformate or mixtures thereof having a boiling point below about 300°C under atmospheric pressure. These
- 45 can be used in anhydrous form or preferably in commercial form which is not free of water, but no additional water is added.

The nanocrystalline lithium titanate spinels of the present invention generally have a particle size of from 1 to 200 nm, preferably from 1 to 50 nm, particularly preferably from 1 to 20 nm, in particular from 1 to 15 nm, especially preferably from 1 to 10 nm, very particularly preferably from 2 to 8 nm.

The nanocrystalline lithium titanate spinels of the present invention are suitable as anode material for rechargeable lithium batteries.

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For use of the nanocrystalline lithium titanate spinels of the present invention as anode material for rechargeable lithium batteries, the spinel material can be sintered at from 350 to 700°C, preferably from 400 to 690°C, more preferably from 450 to 680°C.

#### Examples

##### Example 1

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Under a nitrogen atmosphere, 110 g of butyl glycol, 5 x 1/30 mol, altogether 55.8 g, of titanium tetrabutoxide, 4 x 1/30 mol, altogether 3.2 g, of anhydrous lithium hydroxide and 8 x 1/30 mol, altogether 16.0 g, of acetic acid were combined while stirring and reacted at 120°C for 24 hours. A white suspension was obtained after cooling. The primary particle size of the  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  formed was 1-3 nm.

##### Example 1a

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Part of the suspension obtained in Example 1 was dried. It was examined by means of a heated X-ray camera to determine the temperature at which narrowing of the X-ray reflections commences, which is a temperature at which densification of the material generally commences. In the present example, this temperature is in the range from 500 to 600°C, while establishment of crystalline order is complete above about 400°C.

##### Example 2

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The reaction was carried out in a manner analogous to Example 1, but 10 x 1/30 mol of acetic acid was used. The dispersion obtained was more viscous than that of Example 1. The primary particle size of the  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  formed was 1-3 nm. However, the primary particles were joined to form larger aggregates than in Example 1.

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## Example 3

The reaction was carried out in a manner analogous to Example 1, but 12 x 1/30 mol of acetic acid was used. The dispersion

- 5 obtained was more viscous than that of Example 2. The primary particle size of the  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  formed was 2-4 nm. However, the primary particles were joined to form larger aggregates than in Example 2.

## 10 Example 4

The reaction was carried out in a manner analogous to Example 1, but 16 x 1/30 mol of acetic acid was used. The dispersion

- obtained was more viscous than that of Example 3. The primary  
15 particle size of the  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  formed was 2-4 nm. However, the primary particles were joined to form larger aggregates than in Example 3.

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